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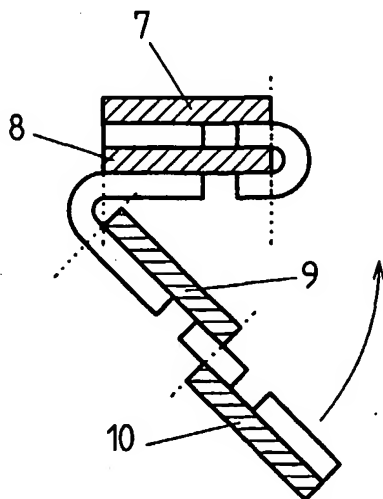
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(54) Title: MULTILAYER CIRCUIT AND METHOD OF MANUFACTURING



(57) Abstract: The invention relates to the manufacturing of a multilayer structure and especially it relates to the manufacturing of a three-dimensional structure and its use as an electronics assembly substrate and as a winding for transformers and inductors. When a multilayer structure is manufactured by folding a conductor-insulator-conductor laminate, where the conductor layers to be separated from each other follow each other on opposite sides of the conductor-insulator-conductor laminate in the sections following each other and where the insulator has been removed from the places where the conductor layers are to be connected together after folding, it is possible to manufacture a wide range of three-dimensional multilayer structures where the volume occupied by the windings over the total volume can be maximized. Alternatively, by using the method it is also possible to manufacture a multilayer structure where components have been buried inside. The method makes it also possible to make connections between layers in a flexible manner. Among other issues, the method can be easily automated for mass-pro-  
duction.

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## Multilayer circuit and method of manufacturing

The invention relates to the manufacturing of a multilayer structure and in particular to the manufacturing of a three dimensional structure and its use as an electronics assembly substrate and as a winding  
5 for transformers and inductors.

Printed circuit boards are often used in electronics as substrate and to form electrical connections between components. Most commonly such circuit boards are manufactured by etching the preferred conductor pattern on a copper-insulator (copper-FR4) laminate and by drilling holes  
10 and through-plating them in order to form electrical connections from one side of the circuit board to the other. Multilayer printed circuit boards are manufactured by stacking and connecting multiples of such boards on top of each other with prepreg-layers under heat and compression.

Such an assembly process is usually manual and includes many  
15 critical operations, in particular concerning the alignment between the layers. In patent application GB 2 255 451 it is shown how the layers to be stacked together are aligned by using special "alignment pins". In patent application WO 98/15160 a completely automatic assembly process based on use of a continuous strip of material is shown.

20 Multilayer printed circuit boards are also used for inductive components such as inductors and transformer windings. The benefit of such a planar inductive component is for example its low profile and high power density.

In patent applications EP0689214, WO01/16970, US5781093 and  
25 US5521573, it is shown how such a planar winding is manufactured by stacking conductor layers on top of each other and by connecting the different layers in proper fashion. Between conductor layers, an insulator may also be placed in order to keep conductors separated and to prevent short circuits. However, in practice such a structure is difficult to  
30 manufacture, which results in high manufacturing costs. Further, because

of the use of many insulator layers, the copper fill factor i.e. the ratio of copper volume to the total volume available for the windings may remain low. This increases the losses and reduces the power density of a transformer. Also, the contact bolts and plated through holes for  
5 connections take away space from actual windings.

An alternative method for manufacturing a multilayer winding structure has been presented for example in patent applications US3484731, US5801611, EP0786784, US5276421 and US5017902, where a thin and flexible insulator-conductor laminate is folded (z-folding, zigzag  
10 folding) several times to form a multilayer structure. In these solutions as well, an insulating layer has to be placed on the laminate prior to folding, which reduces the copper fill factor and thus the transformer power density and also makes the manufacturing process more complicated.

One aim of the present invention is to make the manufacture of  
15 such multilayer structures easier and to increase the power density of inductive components manufactured. Such aim is achieved by the device provided by claim 1 and by the method provided by claim 15.

By using the method according to invention it is possible to manufacture three-dimensional multilayer structures with high a copper fill  
20 factor in a flexible manner. Alternatively, it is also possible to manufacture a multilayer structure into which components have been buried. The method allows connections to be formed conveniently between winding layers. The method is also easy to automate for mass production.

In an embodiment of the invention, the multilayer structure is  
25 manufactured by using a copper-kapton-copper laminate with a reel-to-reel type process. First the winding patterns are formed to the laminate by chemical etching. The laminate consists of consecutive segments corresponding to the separate layers of the final multilayer structure; the copper is removed at least from the points that are later to be connected to  
30 other layers on the top side of even numbered segments and on the bottom side of odd numbered segments. In addition to this, copper is also

removed to form winding patterns. Next the kapton insulator is removed from appropriate places, for example where contacts between winding layers are later to be formed. This may also be done using photolithography. After this, the laminate is folded and compressed along the edges of the imagined segments. Winding layers are then connected together by using a rivet or by an equivalent connection means, like a solder joint.

In another embodiment of the invention, other electronics components have also been connected to the laminate before folding and at least some of these components will be buried inside the multilayer structure when the laminate is folded.

A planar component or integrated power converter can be manufactured by placing ferrite halves around the multilayer winding structure.

The invention will now be explained in more detail with reference to the following illustrative figures where:

Figure 1 illustrates a conductor-insulator-conductor laminate 1 as a three-dimensional projection where also the edges 5 of the imagined segments have been marked;

Figure 2 illustrates a conductor-insulator-conductor laminate 1 as a side view where the edges 5 of the imagined segments have been marked;

Figure 3 illustrates a conductor-insulator-conductor laminate 1 as a side view where the edges 5 of the imagined segments have been marked after copper has been removed from the top and bottom side of the laminate;

Figure 4 illustrates a conductor-insulator-conductor laminate 1 as a side view after copper has been removed from the top and bottom side

of the laminate and also some insulator has been removed from the places 6;

Figure 5 illustrates how the segments 7 and 8 are folded relative to each other;

5            Figure 6 illustrates how the segments 9 and 10 are folded relative to each other;

Figure 7 illustrates how the segments 11 and 12 are folded relative to each other;

10           Figure 8 illustrates a folded multilayer structure with conductor layers 13, insulator layers 14 and interconnection apertures 15;

Figure 9 illustrates a multilayer structure where conductor layers 13 are connected with a rivet 16 which also has an extension for further mounting purposes;

15           Figures 10 A and B illustrate how the copper thickness can be doubled when a conductor 17 is used in the both side of the laminate;

Figures 11 A,B and C illustrate how a solder connection 22 is made between conductor layers 18 to a point 19 where the insulator has been removed by plating the conductors with solder 20 and by pressing them together with a hot tool 21;

20           Figure 12 illustrates how a conductor extension 23 is flipped under the multilayer structure 24 for connection purposes;

Figure 13 illustrates how a contact can be formed between a conductor layer 26 and a circuit board 27 by using a mechanically formed dimple 28 or interconnection ball 29;

Figure 14 illustrates a processed laminate in layer by layer fashion as seen from the top with a top side conductor layer 30, an insulator 31 and a bottom side conductor layer 32, some components 33, 34 having also been connected to said laminate;

5                Figure 15 illustrates the side projection of the laminate of Figure 14 along projection A – B;

Figure 16 illustrates a folded multilayer structure which also has electrical components 33, 34 in it.

10              Figures 17a and 17b illustrate two multilayer structures according to the invention in their unfolded state.

Reel-to-reel type processing is effective to use in manufacturing. The laminate is guided through the different process steps as a continuous strip. This eliminates many manual handling and alignment problems. Semi-finished products can also be stored and shipped between the various  
15    process steps in/on the reels. In Figure 1, a projection of copper-kapton-copper laminate 1 (commonly called FLEX-laminate) is shown with copper 2, 4 and kapton 3 thicknesses of 75µm and 25µm, respectively. In Figure 2, a cross section of such a laminate is also shown. Laminate like this is available on reels and its further processing is easy to automate. The intention is to  
20    process the laminate into the segments 5 which finally form the layers of the multilayer structure.

Processing begins as shown in Figure 3 by forming the intended conductor pattern into to conductor layers 2 and 4 so that the conductor is alternately removed from the bottom and top sides of the insulator 3 from  
25    each segment. Generally speaking, this occurs at least from the places where connections between conductor layers will later be formed. The intention of the figures here is only to illustrate the manufacturing method, and the details of the conductor patterns are not considered. The removal of the conductor in places 2 and 4 reveals the insulating layer 3  
30    where apertures 6 can be made into the insulator 3 according to Figure 4.

Apertures 6 can be formed for example by mechanical drilling, with laser or by etching with plasma or suitable chemical etching bath. It is also possible to pattern conductor layers 2 and 4 in multiple steps and for example to use conductor layers 2 and 4 as etching masks when apertures 6 are formed into insulator 3. The insulator 3 can also be etched in multiple steps. Other electronics manufacturing methods, such as additive conductor build up, photo-definable insulation; mechanical forming and lamination methods can also be used. Various different insulator, conductor and solder materials can also be used in manufacturing.

10           The processed laminate is next folded stage by stage according to Figures 5, 6 and 7 resulting in a multilayer structure (Figure 8) where the insulator 14 and the conductor 13 layers alternate. The laminate bends easily at the right place as the discontinuous conductor layers form a place for bending and also align the layers to some degree.

15           As seen in Figures 5 – 8, the alternation of conductor segments on different sides of the laminate results in inherent insulation between the conductor layers. Also, at no stage did an insulation layer need to be placed on the conductors. This reduces the thickness of the multilayer structure, when compared with the known structures obtained with other methods requiring an additional insulator layers. As additional insulator layers are not needed, the copper fill factor and the power density are increased. The winding layers following each other are also insulated from each other at the segment edges at folding lines due to the folded but continuous insulator. Folding does not have to be done in one direction only but can be accomplished at any other angle or angles to the main direction of laminate as well.

          The winding layers on top of each other are seen individually through the apertures 15, and the winding layers 13 can be contacted together for example with a rivet which punches the conductors at the apertures according to Figure 9. The rivet is formed to provide soldering possibility to a printed circuit board as well.

The above-mentioned multilayer structure can also be manufactured in a manner where, at the segments following each other, there is first conductor on both sides of the laminate and then there is a segment without conductor on any side. However, in this case the access to the insulation layer for processing may be more difficult than as mentioned above.

Also, in some cases prepatterned copper strips may be laminated on a sheet of kapton, in order to directly obtain the printed FLEX laminate without the above etching process.

10 The apertures 6 may also be formed on the kapton before the lamination of the conductive layers.

A multilayer circuit according to the invention comprises therefore a flexible sheet of insulating material 3 having two sides, wherein sections of electrical circuit 7,8,9 are attached to both of said two sides, wherein said flexible sheet 3 is folded along folding lines 5, which divide said flexible sheet 3 into consecutive segments, in order to form a multilayer structure comprising conductor layers 13 and insulator layers 14 stacked above each other.

20 In a variant of the invention at least two consecutive sections of electric circuit that must be insulated from each other are disposed on different sides of said flexible sheet 3.

In another variant of the invention the greater part of the consecutive sections of electric circuit that must be insulated from each other are disposed on different sides of said flexible sheet 3.

25 In another variant of the invention special arrangements will be required for the top and bottom layers, and all consecutive sections of electric circuit not lying on said top and bottom layers and that must be insulated from each other are disposed on different sides of said flexible sheet 3.



Finally, in another variant of the invention, all consecutive sections of electric circuit not lying on said top and bottom layers and that must be insulated from each other are disposed on different sides of said flexible sheet 3.

5 In Figures 10A and 10B, it is shown how the conductor thickness of a multilayer structure can be doubled, for example to reduce winding resistance, but by still using a laminate with the original copper thickness. The conductor has been removed especially on the top of the right side segment. On the left side, the conductor has been removed only to give  
10 access to the insulator for processing; if compared with the laminate in Figure 3, it should be noted that the conductor 17 is now located below the left side segment.

After folding, this conductor will contact with the conductor in the next segment and, in this case, they will be placed on top of each other  
15 resulting in the copper thickness doubling. In other words, the conductor patterns on the same side of the segments following each other can be connected together. If the layers connected to each other are further contacted permanently together, for example by using a soldered connection, the mechanical stability of the folded structure will be  
20 improved.

Apart from the rivet contact presented above, a more flexible and efficient method is to contact consequent winding layers together already as the folding proceeds. This makes it possible to manufacture so called "buried vias" where only some of the winding layers come in contact  
25 together at each connection point. In Figure 11 A, the contact points 19 of the conductor patterns 18 have been plated with solder 20. In Figure 11 B, the conductor layers are pressed together for contact 22 using a tool 21. The tool can for example be a soldering iron or an ultrasound tool. The finished connection according to Figure 11C is reliable since the flexibility  
30 of the multilayer structure reduces stresses that may for example be due to thermal expansion. The method also does not require the realization of plated through holes. Low contact resistance between layers can be

obtained. As an additional benefit, connections between layers stabilize the structure. Folding edges outside the structure, or some of them, can be cut away after folding. Conductor layers can also be mechanically formed, for example to have extensions or dimples which can then connect  
5 together and form a connection. Apertures 6 can also be filled with solder paste or solder to form interconnections by simply heating the folded structure.

In order to connect the finished multilayer structure 24 to the circuit board as a surface mounted component, it can be provided with a  
10 solder extension 23 which is then folded under the component to position 25 according to Figures 12A, 12B and 12C. Some layers of the structure can also be provided with mechanical dimples 28 or connection terminals 26 or interconnection balls 29 to provide electrical and mechanical contact to the substrate. A conductor pattern on the outermost surface may also be used  
15 as sufficient interconnection surface. Connection extensions 23 can be used to provide both internal and external connections to the multilayer structure.

Figures 17a and 17b illustrate two further embodiment of the present invention, in which the flexible etched laminate is shown in its  
20 unfolded state, before the folding operation.

Figure 17a shows a circuit in which each of the segment of circuit 7,8,9 constitutes one turn each, and all the turns are connected in series in order to form a high-inductance coil. While the structure is folded, electrical connections between segments of circuit are realized at the  
25 etched apertures 6 by the creation of "buried vias", for example by the method explained in the precedent embodiment. The center holes are found in aligned positions once the folding is complete and allow the insertion, for example, of a magnetic core.

Figure 17b shows another circuit in which each segment of circuit  
30 7,8,9 constitutes one turn each, and all the turns are connected in parallel, in order to form a coil of high current capability. In this case all the etched

apertures 6 corresponding to one pole of the coil are aligned; and the connection can be obtained with the insertion of rivets, like in the method illustrated in fig. 9

By adding magnetic components such as ferrites to the multilayer structure, an inductive component is obtained. Ferrite components can be attached to the structure before or after the folding.

The method makes it possible to manufacture other components such as capacitors and resistors and combinations thereof such as integrated LC-components, as well as for example to make filters of small size. In other words, the conductors of the multilayer structure can also be used both as windings of an inductive component and as capacitor plates of a capacitor. It may also be efficient to use the same laminate to manufacture multiple separate components at the same time.

In another embodiment of the invention, the multilayer structure includes besides the conductor and insulator layers other electrical components assembled therein. Figure 14 illustrates a processed laminate with various layers separated from each other. The top side conductor layer 30 has a component 33 mounted on it and, similarly, the bottom side conductor 32 has a component 34 on it. The conductor layers 30 and 32 and the insulator layer have large material removal apertures in them. The side projection along A – B is shown in Figure 15. Figure 16 illustrates a multilayer structure where a first component 33 is outside the structure and a second component 34 is inside a cavity formed by the apertures in the conductor and insulator layers. Burying components inside multilayer structures reduces the size of the assemblage. It is also possible to shield noise components inside the structure to reduce electromagnetic interference.

The components can be traditional through-hole or surface-mounted components or more advanced flip-chip components and passive thin and thick film components. It is especially beneficial to include components of switched mode power supplies into the inductive

components. The insulator can also be used for guiding light, for example for communication between different parts of the structure. The cavities which can be formed inside the structure can be used for cooling. Especially the increase of the structure surface area by cavities or apertures promotes  
5 cooling.

### Claims

1. Multilayer circuit comprising a flexible sheet of insulating material (3) having two sides, wherein sections of electrical circuit (7,8,9) are attached to both of said two sides, wherein said flexible sheet (3) is  
5 folded along folding lines (5), which divide said flexible sheet (3) into consecutive segments, in order to form a multilayer structure comprising conductor layers (13) and insulator layers (14) stacked above each other, characterized in that at least two consecutive sections of electric circuit that must be insulated from each other are disposed on different sides of said  
10 flexible sheet (3).
2. Multilayer circuit according to claim 1 further characterized in that consecutive sections of electric circuit that must be insulated from each other are insulated by one single ply of said flexible sheet (3).
3. Multilayer circuit according to claim 1 or 2, further  
15 characterized in that consecutive sections of electric circuit that must be insulated from each other lie on opposite sides of said folding flexible sheet (3), on adjacent segments of said flexible sheet (3).
4. Multilayer circuit according to one of the preceding claims, further characterized in that sections of electric circuit that must not be  
20 insulated from each other lie on the same side of said folding flexible sheet (3), on adjacent segments of said flexible sheet (3).
5. Multilayer circuit according to one of the preceding claims, further comprising electrical connection means (16, 20) between said conductor layers (13).
- 25 6. Multilayer circuit according to claim 5, further comprising apertures (6, 15) in said flexible sheet (3) in correspondence with said electrical connection means (16, 20).

7. Multilayer circuit according to claim 5, further characterized in that said electrical connection means is a rivet (16).

8. Multilayer circuit according to claim 5, further characterized in that said electrical connection means is a solder joint or a solder layer (20).

5 9. Multilayer circuit according to one of the preceding claims, further characterized in that said conductor layer (13) has at a discontinuity in correspondence with the folding lines (5), in order to guide the folding.

10. Multilayer circuit according to one of the preceding claims further characterized in that it includes magnetic components.

10 11. Multilayer circuit according to one of the preceding claims further characterized in that it include electric or electronic components (33).

12. Multilayer circuit according to the preceding claim further characterized in that said electronic components (33) are inside said  
15 multilayer structure.

13. Multilayer circuit according to one of the preceding claims further characterized in that it contains cavity and apertures.

14. Multilayer circuit according to one of the preceding claims further characterized in that it is configured to form an inductor or an  
20 electrical transformer or an electrical filter.

15. Manufacturing method for a multilayer circuit, comprising the steps of:

- obtaining a conductor-insulator-conductor laminate (1) having a central insulator flexible sheet (3) and carrying circuit segments on  
25 both sides of said flexible sheet (3) in a fashion that consecutive sections of electric circuit that must be insulated from each other are disposed on different sides of said flexible sheet (3);

- folding said laminate (1) along folding lines (5), which divide said flexible sheet (3) into consecutive segments, in order to form a multilayer structure comprising conductor layers (13) and insulator layers (14) stacked above each other.

5        16.        Manufacturing method according to claim 15 wherein said step of obtaining said conductor-insulator-conductor laminate (1) further comprises the step of selectively removing conductor areas from said conductor-insulator-conductor laminate (1).

10        17.        Manufacturing method according to claim 15 wherein said step of obtaining said conductor-insulator-conductor laminate (1) further comprises the steps of :  
- cutting a sheet of conductive material (2,4) into a predefined pattern;  
- laminating said predefined pattern of conductive material on  
15 a sheet of a flexible insulator (3).

18.        Manufacturing method according to the one of the claims from 15 to 17 claim further comprising the steps of:  
- creating apertures (6, 15) in said flexible sheet, in  
correspondence to places where said sections of electric circuit must be  
20 joined;  
- placing electrical connection means (16, 20) to join said sections of electric circuit in said apertures (6, 15).

19.        Manufacturing method according to the previous claim wherein said electrical connection means is a solder layer (20) and further  
25 comprising the step of melting said solder to obtain an electrical connection.

20.        Manufacturing method according any of the claims 15 to 19 wherein several of said multilayer circuits are formed at the same time from said laminate (1).

21. Manufacturing method according any of the claims 15 to 20 wherein the laminate (1) is guided through the different process steps as a continuous strip.



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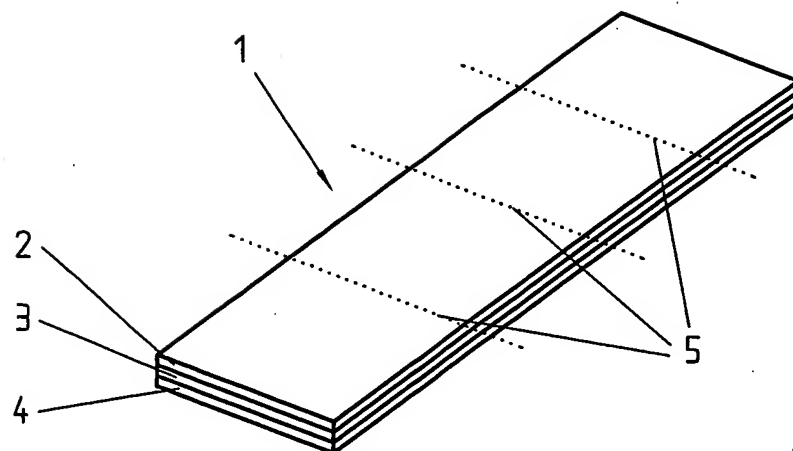


Fig. 1

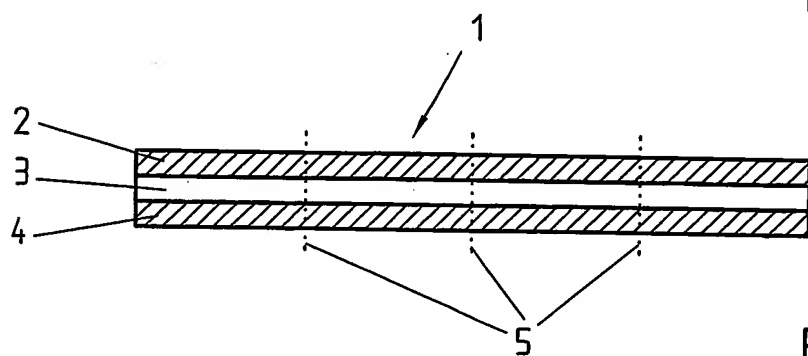


Fig. 2

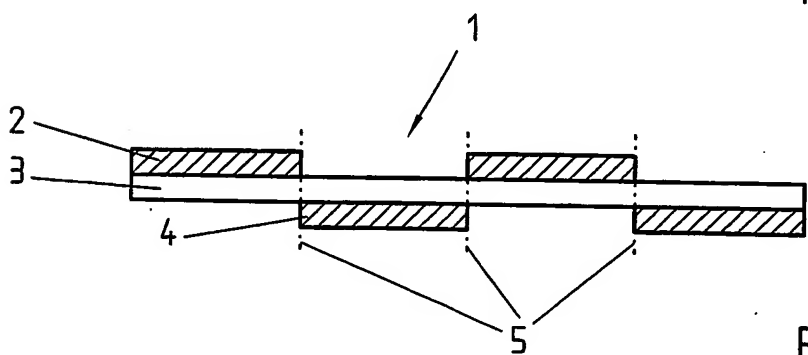


Fig. 3

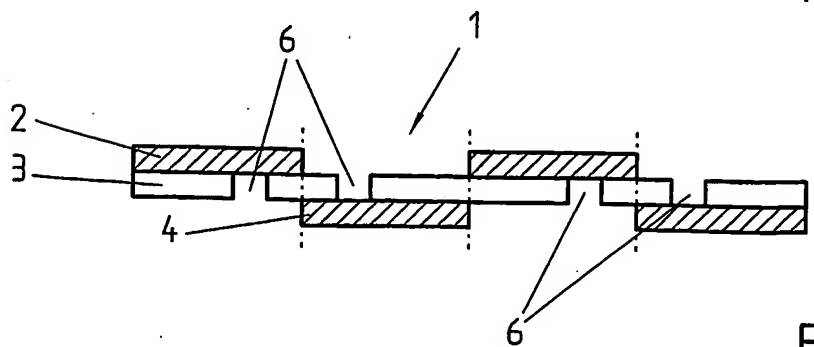


Fig. 4

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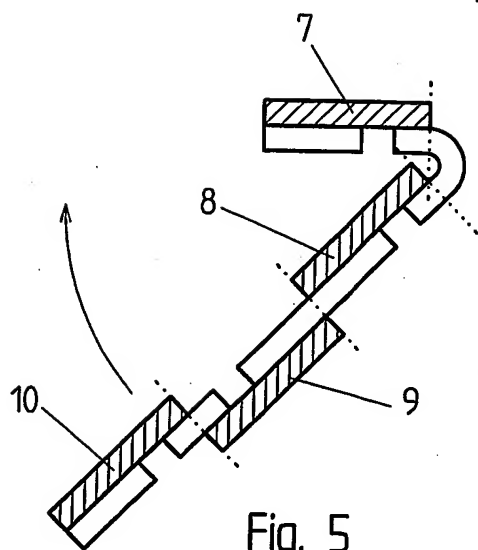


Fig. 5

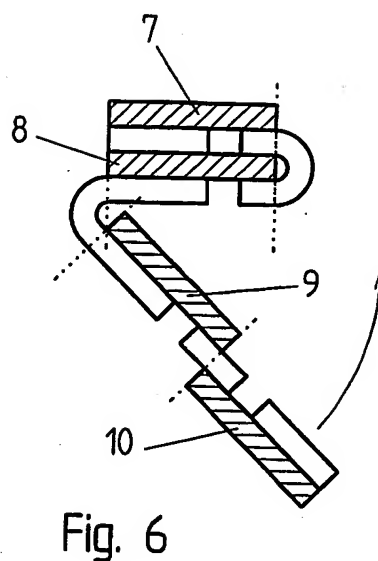


Fig. 6

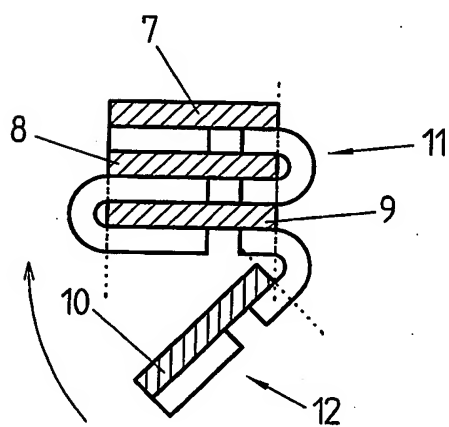


Fig. 7

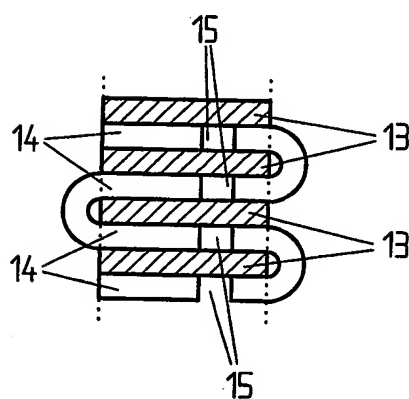


Fig. 8

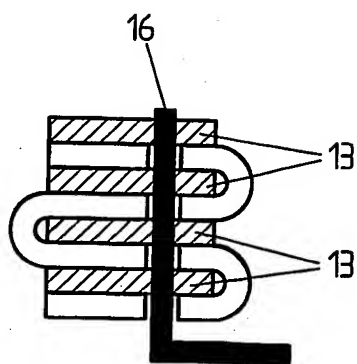


Fig. 9

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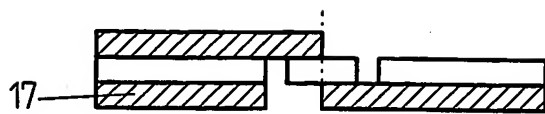


Fig. 10a

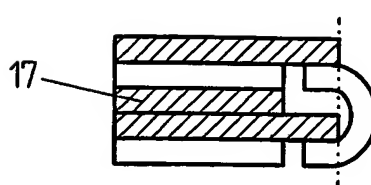


Fig. 10b

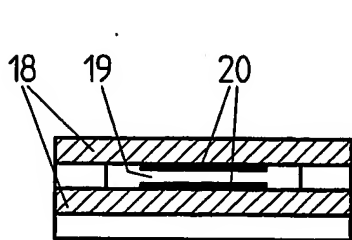


Fig. 11a

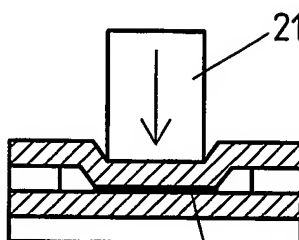


Fig. 11b

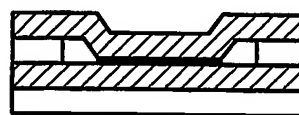


Fig. 11c

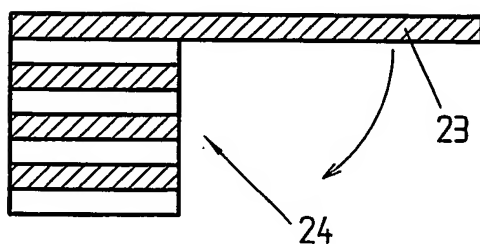


Fig. 12a

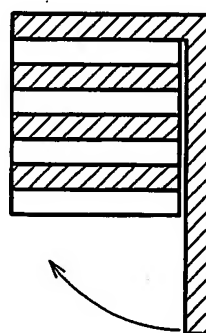


Fig. 12b

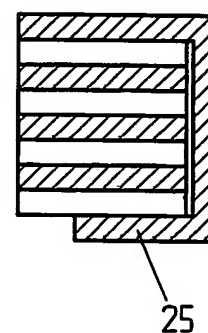


Fig. 12c

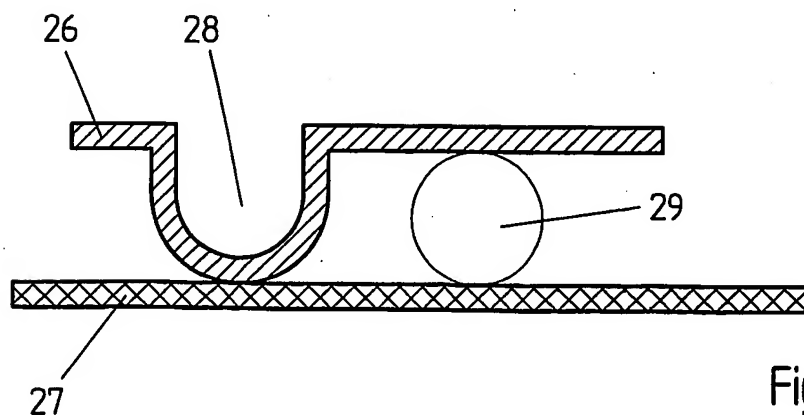


Fig. 13

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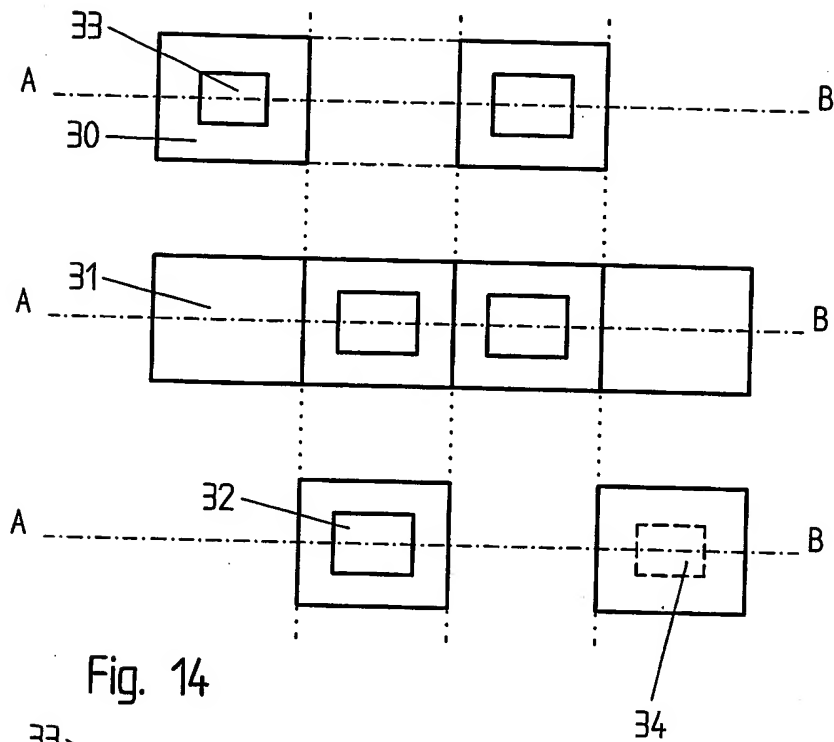


Fig. 14

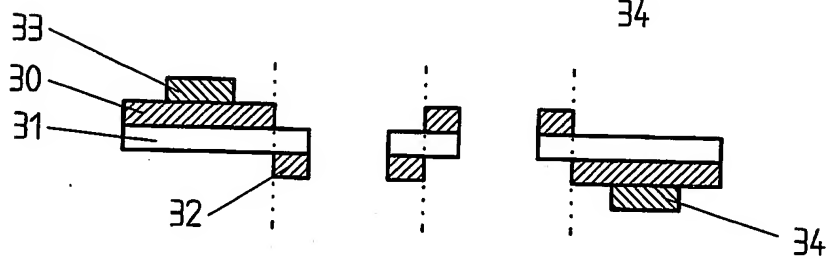


Fig. 15

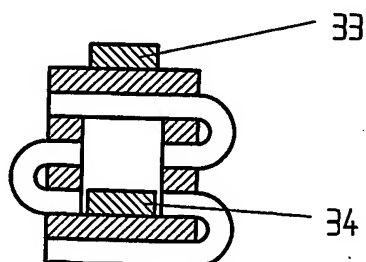
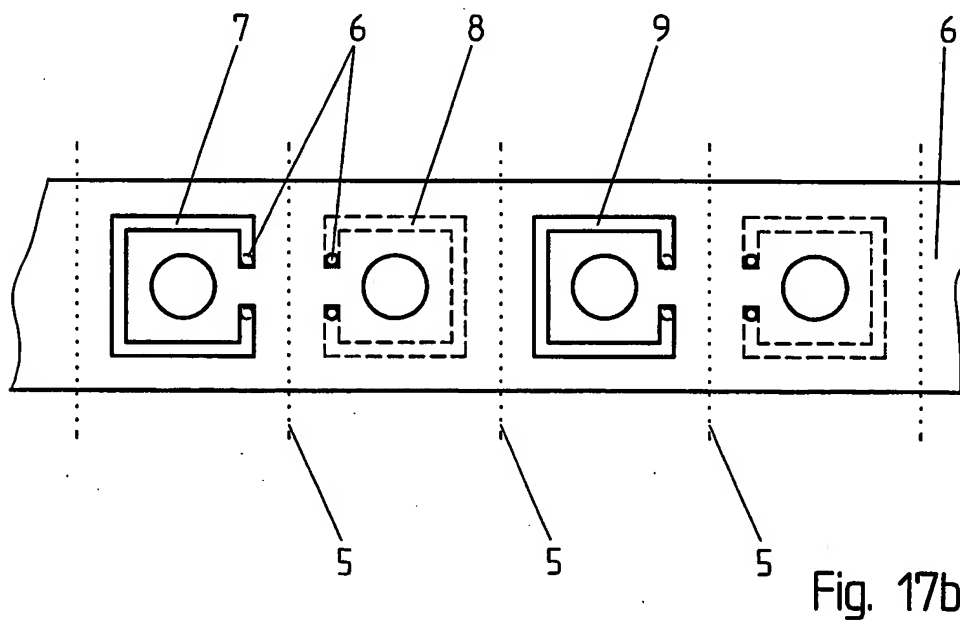
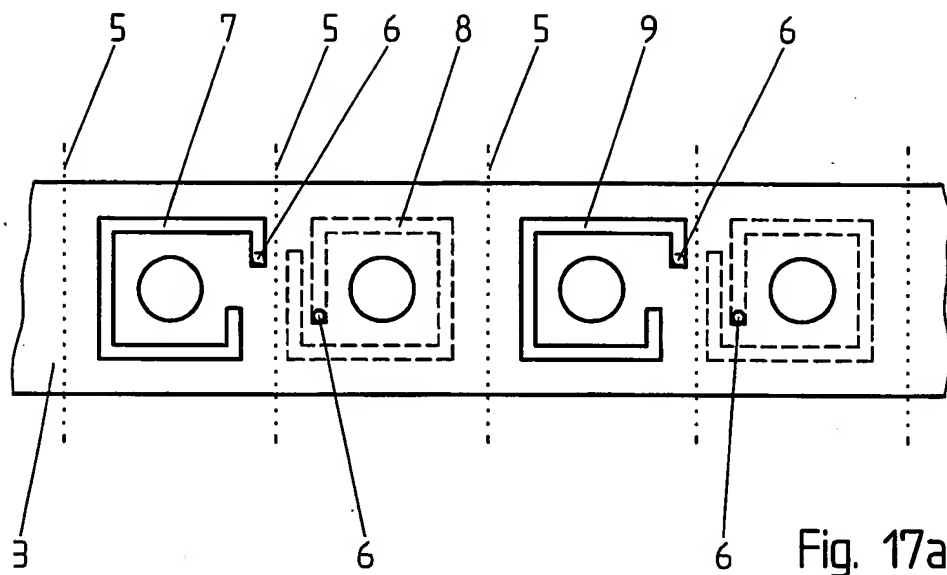


Fig. 16

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# INTERNATIONAL SEARCH REPORT

International Application No  
PCT/EP 02/11839

**A. CLASSIFICATION OF SUBJECT MATTER**  
IPC 7 H01F27/28 H05K3/36

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)  
IPC 7 H05K H01F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP 0 035 964 A (WALCH RUDOLF) 16 September 1981 (1981-09-16) the whole document	1-21
A	US 5 381 124 A (ROSHEN WASEEM A) 10 January 1995 (1995-01-10) the whole document	1-21

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

\* Special categories of cited documents:

- \*A\* document defining the general state of the art which is not considered to be of particular relevance
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- \*O\* document referring to an oral disclosure, use, exhibition or other means
- \*P\* document published prior to the international filing date but later than the priority date claimed

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Date of the actual completion of the international search

18 February 2003

Date of mailing of the international search report

27/02/2003

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Van Reeth, K

# INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No

PCT/EP 02/11839

Patent document cited in search report		Publication date	Patent family member(s)	Publication date
EP 0035964	A	16-09-1981	EP 0035964 A1	16-09-1981
US 5381124	A	10-01-1995	CA 2137589 A1	30-06-1995
			EP 0661722 A1	05-07-1995
			JP 7263258 A	13-10-1995

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